

A GAMMA-RAY BURST REMNANT IN OUR GALAXY: HESS J1303-631

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ABSTRACT

We present an investigation of the multiwavelength data on HESS J1303-631, an unidentified TeV source serendipitously discovered in the Galactic plane by the HESS collaboration. Our results strongly suggest the identification of this particular source as the remnant of a Gamma-Ray Burst (GRB) that happened some few tens of thousands years ago in our Galaxy at a distance on the order of $\gtrsim 10$ kpc from us. We show through detailed calculations of particle diffusion, interaction and radiation processes of relativistic particles in the interstellar medium, that it is possible for a GRB remnant (GRBR) to be a strong TeV emitter with no observable synchrotron emission. We predict spectral and spatial signatures that would unambiguously distinguish GRBRs from ordinary supernova remnants, including: (1) large energy budgets inferred from their TeV emission, but at the same time (2) suppressed fluxes in the radio through GeV wavebands; (3) extended center-filled emission with an energy-dependent spatial profile; and (4) a possible elongation in the direction of the past pair of GRB jets. While GRBRs can best be detected by ground-based gamma-ray detectors, the future GLAST mission will play a crucial role in confirming the predicted low level of GeV emission.

Subject headings: cosmic rays — diffusion — gamma-rays: bursts — — supernova remnants

1. INTRODUCTION AND OUTLINE

So far, GRBs have only been identified at cosmological distances. It is believed that GRBs are caused by highly relativistic outflows with bulk Lorentz factors $\Gamma \gtrsim 100$ that form a pair of opposite jets. Even after correcting for narrow beaming, the energy radiated by long-duration (≥ 2 s) GRBs typically is $\sim 10^{51}$ erg, and the estimated kinetic energy of the jets reaches values of $\sim 10^{52}$ erg (Mészáros 2002; Bloom et al. 2003; Berger et al. 2004). Relativistic shocks convert (accelerate) *all* particles from the incoming plasma they encounter to relativistic energies by randomizing their velocities in the comoving frame. In the stationary frame the mean energy per particle is $\bar{E} \simeq m_p c^2 \Gamma^2 / 2$ (Blandford & McKee 1976). The total energy of cosmic rays (CRs) produced by a GRB can thus be up to ~ 100 times higher than the $\sim 10^{50}$ erg produced by nonrelativistic shocks of typical supernova remnants (SNR) (Berezinsky et al. 1990). GRBs are prime candidate sources for the extragalactic component of CRs, and they may also be sources of ultrahigh energy CRs in our Galaxy (Dermer 2002). Calculations taking into account the star formation history and the GRB beaming factor predict a Galactic rate of one long GRB every 3000 to 10^5 years (Wick et al. 2004; Dermer & Holmes 2005). A GRB that occurred ~ 1 Myr ago at $\lesssim 1$ kpc from us could explain the knee in the observed CR spectrum at $E \gtrsim 10^{15}$ eV (Wick et al. 2004). Others have suggested that giant radio shell objects in the Milky Way, such as the SNR W49B (see Ioka et al. 2004) or kpc-size HI super-shells (Efremov et al. 1998) could be remnants of GRBs.

The HESS (High Energy Stereoscopic System) collaboration has recently discovered a population of γ -ray sources in the Galactic plane (Aharonian et al. 2005b, 2006) that are TeV-bright but are often quiet in all other wavelengths and remain unidentified. All previously detected TeV sources show strong X-ray emission which is the synchrotron counterpart of the Inverse Compton (IC) TeV radiation from multi-TeV electrons. The suppression of low-frequency flux is unexpected

within conventional models. Mitra (2005) has proposed that this feature points to radiation production in the deep gravitational potential wells of black holes formed by Galactic GRBs. However, the extended appearance of these sources seems to contradict this explanation.

The estimated rate of Galactic GRBs implies a likelihood of between one and several “young” (age $t \gtrsim 10^4$ yr), GRB remnants in the interstellar medium (ISM) at distances up to $d \sim 10$ – 20 kpc from us. Some $\gtrsim 10^4$ years after their acceleration by the relativistic shocks of GRBs, multi-TeV particles would diffuse over distances of about $\gtrsim 100$ pc. Therefore, if detected in TeV γ -rays, Galactic GRBRs should appear as large plerionic (‘center-filled’) nebulae in the ISM.

While probably most of the unidentified TeV sources would eventually be associated with conventional Galactic objects, here we argue that at least one source, HESS J1303-631 (Aharonian et al. 2005a), shows features that strongly suggest its identification with the remnant of a GRB that happened $\gtrsim 10^4$ (4d/c) years ago in our Galaxy at a distance $d \simeq (10$ – $15)$ kpc from us. We show that this can explain both the total CR energy in the source, and its non-detection below TeV energies. Furthermore, we discuss observational signatures that can be used to identify GRBRs unambiguously.

2. INVESTIGATION OF THE TEV ENERGY SPECTRUM

Among the unidentified TeV sources discovered by HESS, J1303-631 is the brightest source with the most detailed data (Aharonian et al. 2005a). The measured (0.38–12) TeV differential spectrum, approximated as a power-law $F(E) \propto E^{-\alpha_\gamma}$, has a mean spectral index $\alpha_\gamma \approx 2.44$ and an integrated energy flux $f_E \approx 1.87 \times 10^{-11}$ erg cm⁻² s⁻¹. So far, no emission has been detected in any other wave band, including the X-ray band (Mukherjee & Halpern 2005). The source is extended and is approximated, within current statistical errors, by a spherically symmetric 2-dimensional Gaussian distribution with inherent width $\theta_{\text{src}} = 9'.6$ (Aharonian et al. 2005a). The center-filled appearance of the source and the gradual steepening of the TeV spectrum suggest the emission origin

from a population of high-energy particles injected into the ISM from a point source and evolved by energy-dependent diffusion.

Absence of a detectable synchrotron flux implicitly suggests a hadronic origin of the TeV radiation. Since the two γ -rays from a π^0 -decay each carry a fraction of the incident proton energy of about $E_\gamma \simeq 0.075 E_p$, the observed flux requires $U_p \simeq 4\pi d^2 f_E t_{pp} \eta_0^{-1}$ total energy in protons with $E_p \gtrsim 5$ TeV. Here, $t_{pp} = (K_{pp} \sigma_{pp} c n_H)^{-1}$ is the pp -cooling time, and $\eta_0 \simeq 1/3$ is the fraction of the lost proton energy that is converted into π^0 -mesons. Substitution of the cross-section $\sigma_{pp} \simeq 40$ mb and the inelasticity $K_{pp} \simeq 0.5$ gives

$$U_p \simeq 1.2 \times 10^{49} d_{\text{kpc}}^2 n_H^{-1} (1+S) \text{ erg}. \quad (1)$$

Here $d_{\text{kpc}} = d/1 \text{ kpc}$, and S accounts for protons with $E \leq 5$ TeV. For standard SNR acceleration, a broken power-law spectrum with $\alpha_2 \simeq 2.44$ above and $\alpha_1 = 2.0$ below 5 TeV gives the smallest possible $S \approx 4.9$. A more plausible SNR spectrum with $\alpha_1 = 2.2$ predicts $S \approx 24$.

Integration of the proton energy distribution formed by diffusion from a point ‘impulsive’ source (Atoyan et al. 1995) along the line of sight gives $n(E, \theta, t) = N_0(E) \pi^{-1} l_{\text{dif}}^{-2} \exp[-\zeta(E, \theta)/2]$, where $l_{\text{dif}} = \sqrt{2D(E)t}$ is the mean diffusion length (along each of the axes) for a particle with energy E , diffusion coefficient $D(E) = D_{27} 10^{27} (E/10 \text{ GeV})^\delta \text{ cm}^2 \text{ s}^{-1}$ in a power-law approximation, and $\zeta(E, \theta) \equiv (\theta d/l_{\text{dif}})^2$. Integrating over a circle of angular radius θ_s , we derive a proton energy spectrum $N(E; \theta \leq \theta_s) = N_0(E) [1 - \exp(-\zeta(E, \theta_s)/2)]$.

The observed spectral index $\alpha_\gamma = 2.44$ is significantly steeper than $\alpha_1 \approx 2.1$ – 2.2 expected for a typical SNR. We explain this steepening as an unavoidable result of energy dependent diffusion. Given the HESS point spread function (PSF), the derived $N(E; \theta \leq \theta_s)$ suggests $\zeta_0 \equiv \zeta(10 \text{ TeV}, 9'.6) \sim 1$. Calculations nicely fit the data for $\zeta_0 = 0.61$, and exclude $\zeta_0 > 0.8$ or $\zeta_0 < 0.45$ (see Fig. 1). This defines the following key-relation between the source distance and its age $t = t_{\text{kyr}} 10^3 \text{ yr}$ (we count t from the time when the first light from the source reached us, and neglect the source expansion during the light crossing time $2l_{\text{dif}}/c \ll t$):

$$d_{\text{kpc}} = 0.935 \times 10^{3\delta/2} (D_{27} t_{\text{kyr}})^{1/2} \zeta_0^{1/2}. \quad (2)$$

This constrains the energy required to explain both the spectral and the spatial appearance of the source:

$$U_p \approx 1.1 \times 10^{49+3\delta} (1+S) D_{27} t_{\text{kyr}} n_H^{-1} \zeta_0 \text{ erg}. \quad (3)$$

The diffusion coefficient in the ISM should have $\delta \simeq 0.5$ to explain the CR spectral index $\alpha_{\text{CR}} = \alpha_1 + \delta \approx 2.7$. A typical value of $D(E)$ at 10 GeV is $D_{27} \gtrsim 10$ (Berezinsky et al. 1990; Ptuskin & Soutoul 1998). A lower limit of $D_{27} \gtrsim 0.3$ can be derived from the grammage $X \equiv m_p n_H c t_0 \simeq 10 \text{ g cm}^{-2}$ that explains the observed composition of CR nuclei (e.g., Buckley et al. 1994), and does not allow CRs to stay for more than $t_0 \simeq 10^7 \text{ yr}$ in the Galactic disk at heights $h_{\text{disk}} \lesssim 150 \text{ pc}$ where $n_H \gtrsim 0.5 \text{ cm}^{-3}$ (Ptuskin & Soutoul 1998). Values of D_{27} much smaller than the typical ones for the ISM would imply an enhanced level of turbulence and can be excluded, as the associated enhanced magnetic field would result in radio emission exceeding the flux upper limit derived below.

With these results, we are now in the position to argue that the source is a GRBR and not a typical SNR. Using

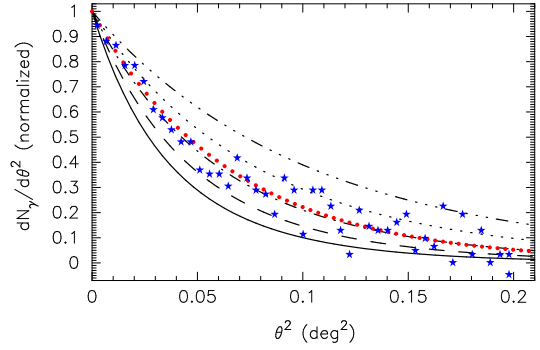


FIG. 1.— Observed (stars) and modelled (lines) angular distributions of γ -rays from HESS J1301-631 (normalized at $\theta = 0$). From bottom to top, the lines show the distributions for $\zeta_0 = 1.22, 0.862, 0.61, 0.43$, and 0.305 , convolved with the PSF $\propto a \exp[-0.5(\theta/2\sigma_1)^2] + b \exp[-0.5(\theta/2\sigma_2)^2]$, with parameters σ_1, σ_2 and a/b derived from the PSF plot in Aharonian et al. (2005a). The full dots show the best-fit to the experimental data in the form of PSF-convolved 2D Gaussian distribution with width $\theta_{\text{src}} = 9.6'$.

$D_{27} \gtrsim 0.3$, we constrain the source age to $t_{\text{kyr}} \lesssim 0.2 d_{\text{kpc}}^2$. Even for a SNR with $\alpha_1 = 2.0$, an age $t_{\text{kyr}} \lesssim 1.8$, and location at $d \sim 3 \text{ kpc}$ in the ISM with $n_H \sim 1 \text{ cm}^{-3}$, equation (1) predicts $U_p \gtrsim 6.4 \times 10^{50} n_H^{-1} \text{ erg}$. For a typical 10% CR injection efficiency by a SNR, this requires a kinetic energy $U_{\text{kin}} \gtrsim 6 \times 10^{51} \text{ erg}$. In principle, such energies cannot be excluded for some extremely powerful supernovae (SNe) of type Ib/c or II_n (which in fact might be GRBs) that constitute $\lesssim 1\%$ of all SNe (e.g. Sveshnikova 2003). This implies a total of $N_{\text{SN}} \lesssim (0.1\text{--}0.3) t_{\text{kyr}}$ such events in our Galaxy. The expected number of such SNRs at a distance $d_{\text{kpc}} \approx 3$ is only $\xi \simeq N_{\text{SN}} (d_{\text{kpc}}/15)^2 \lesssim (0.7\text{--}2.1) \times 10^{-2}$. Furthermore, the non-detection of the shell of such powerful, close and young SNR in the radio and X-ray bands is difficult to explain.

An assumption that the source is an SNR inside a molecular cloud with $n_H = 56 \text{ cm}^{-3}$ at $d = 2.1 \text{ kpc}$ (Aharonian et al. 2005a) relaxes the extremely high SNR energy requirement and increases ξ to acceptable values. However, the problem of the missing shell of this still powerful and young SNR in such a dense medium persists. Even for a total energy in relativistic electrons of about 1% of the protons, which is a typical lower limit for an SNR, the synchrotron flux would significantly exceed the flux upper limit at 5 GHz (see Fig. 3).

For a source age of $t \gtrsim 10^4 \text{ yr}$, equation (2) moves the source to $d \gtrsim 10 \text{ kpc}$ and increases dramatically the energy requirements for an SNR that accelerates particles by non-relativistic shocks. The full radius of the source (detected up to $\theta \lesssim 25'$) increases to $\gtrsim 70 \text{ pc}$ implying that it is located either in ordinary ISM or *entirely* inside (to have a quasi-uniform profile for n_H) a giant molecular cloud. Figure 2 shows the fluxes calculated for $n_H = 1 \text{ cm}^{-3}$, $d = 12 \text{ kpc}$ and $t = 1.5 \times 10^4 \text{ yr}$. Two different proton energy spectra are considered. One implies an ‘extreme SNR’, with $\alpha_2 = 2.2$ at $E \geq E_{\text{brk}} = 5 \text{ TeV}$ but $\alpha_1 = 2.0$ at $E < E_{\text{brk}}$. The total energy derived is $U_{p,\text{SNR}} = 8.1 \times 10^{51} n_H^{-1} \text{ erg}$. The ‘GRBR’ spectrum assumes $\alpha_1 = 1.5$ implying protons accelerated by a relativistic shock. For qualitative estimates the break energy could be defined as $E_{\text{brk}} \sim 0.5 \Gamma_1^2 \text{ GeV}$, where Γ_1 is the shock Lorentz-factor at the time when most of the initial shock energy is transferred to relativistic protons (see Sec. 3). Fitting the data we find $\Gamma_1 \lesssim 100$. Thus Γ_1 can be as high as the *initial* $\Gamma_0 \gtrsim 100$ of GRB jets (Mészáros 2002). Figure 2 assumes $\Gamma_1 = 100$. This reduces the total energy required for the GRBR model to $U_{p,\text{GRBR}} = 4.1 \times 10^{51} n_H^{-1} \text{ erg}$. Values

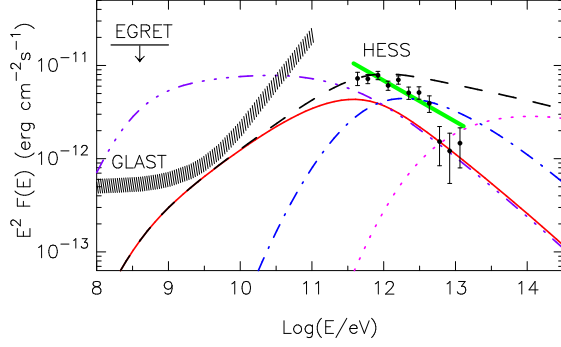


FIG. 2.— Hadronic (π^0 -decay) model of the γ -ray emission from HESS J1301-631, calculated for a GRBR of age $t = 1.5 \times 10^4$ yr at $d = 12$ kpc in the ISM with $n_H = 1 \text{ cm}^{-3}$. Calculations assume a broken, “GRBR type”, power-law proton spectrum, with $\alpha_1 = 1.5$ below $E_{\text{brk}} = 5 \text{ TeV}$. The thick dashed line shows the predicted energy flux when *all* emission within one degree from the source center is considered. The spectrum is considerably harder than the measured one (data points and the bar). Owing to technical difficulties associated with the determination of the energy spectrum of an extended source, the H.E.S.S. collaboration derived the spectrum using only photons detected within the central $13.4'$ radius and scaled it according to the total observed flux. We predict that the energy spectrum derived using all the TeV photons will follow the dashed line. The solid line shows the flux from the intrinsic $\theta \leq 10'$ region (this effectively translates to $13.4'$ size after correcting for the PSF). The dashed-dotted line and the dotted lines show the fluxes from $10'-25'$ and a $25'-1^\circ$ annuli, respectively. The 3-dot-dashed curve is the flux from the inner $10'$ angular region for an SNR-type spectrum of CRs, $\alpha_1 = 2.0$. Upper flux limit of EGRET for HESS J1303-631 (Mukherjee & Halpern 2005) and the 1-yr flux sensitivity of GLAST are also shown.

of $E_{\text{brk}} < 5 \text{ TeV}$, which are not excluded, would lead to an increase $U_{p,\text{GRBR}} \propto (5 \text{ TeV}/E_{\text{brk}})^{0.2}$ (for $E_{\text{brk}} \gtrsim 0.1 \text{ TeV}$), and even slower for $U_{p,\text{SNR}}$.

The HESS collaboration discussed the giant ($r \simeq 144 \text{ pc}$) molecular cloud G303.9-0.4 (Grabelsky et al. 1988) with $n_H \simeq 10\text{--}20 \text{ cm}^{-3}$ located at 12 kpc from us as a possible host of the source. For the SNR-type spectrum, the minimum CR energy $U_{p,\text{SNR}} = (4\text{--}8) \times 10^{50} \text{ erg}$ is problematic even for a very powerful SNR. Furthermore, sub-relativistic protons alone would contain sufficient energy for heating (at a rate $\sim 3 \times 10^{35} \text{ erg s}^{-1}$), and possibly also disintegration, of the cloud via Coulomb losses. Because of the “low-energy cut-off” expected below E_{brk} , these constraints do not apply if HESS J1303-631 is a GRBR. It is also possible that the cloud is merely a line of sight coincidence. Even at a distance of $d = 15 \text{ kpc}$ a GRBR would still be able to power the inferred proton energy density in the ISM.

Leptonic models require less power than hadronic models. IC radiation of multi-TeV electrons on the CMB and Galactic far-infrared photons could reproduce the observed spectrum. A broken power-law electron spectrum with $\alpha_{e,1} = 2.1$ below 10 TeV, and $\alpha_{e,2} = 3.2$ above leads to the minimum required energy $U_e \simeq 2.4 \times 10^{48} d_{\text{kpc}}^2 \text{ erg}$. However, the synchrotron radio flux of the leptonic model exceeds the flux upper limit that we derived from the Parkes-MIT-NRAO southern 4850 MHz survey (Condon et al. 1993) even for an ISM magnetic field $B_{\text{ISM}} = 3 \mu\text{G}$ (see Figure 3). We estimate the limit by measuring a mean flux of 0.0032 Jy/beam in the $9'.6$ radius region centered on the source. Calculating the flux in background regions of the same aperture, we estimate a standard deviation of 0.0033 Jy/beam . Using a beam width of $7'$ FWHM, we then obtain a 5σ upper limit of 0.12 Jy on the flux from within $9'.6$ from the source centroid.

We have also computed the IC fluxes from the sec-

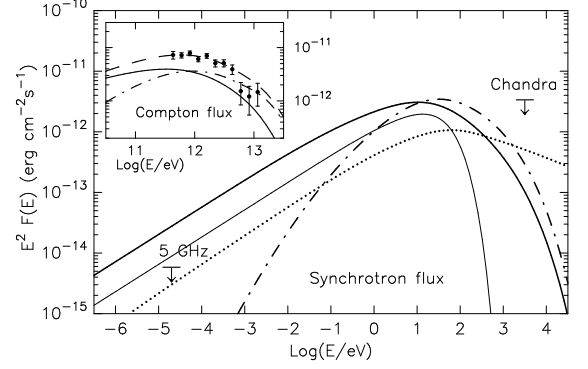


FIG. 3.— Synchrotron fluxes (shown in the main frame) expected from HESS J1301-631 in the case of a leptonic (IC) origin of TeV fluxes (shown in the inset). The fluxes expected from angular distances $\theta \leq 10'$ and $\theta > 10'$ are plotted with heavy solid and dot-dashed lines, respectively. The total IC flux (dashed line) is normalized to the observed flux at 1 TeV. The source age $t = 10^4$ yr and $B = 3 \mu\text{G}$ are assumed. The thin solid curve shows the synchrotron flux from accelerated (primary) electrons with total energy 1% of relativistic protons, to be expected from a SNR at $d = 2.1 \text{ kpc}$ in dense cloud with $n_H = 56 \text{ cm}^{-3}$ (Aharonian et al. 2005a) and enhanced level of turbulence and magnetic field, $B = 10 \mu\text{G}$, where the observed TeV flux would be explained by the protons. The synchrotron radiation from secondary electrons is shown by the full-dotted line.

ondary π^\pm -decay electrons and from β -decay electrons (see Ioka et al. 2004), accounting also for their radiative energy losses. Both fluxes are almost two orders of magnitude lower than the π^0 -decay flux. The ratio of synchrotron to IC fluxes depends only on the ratio of the magnetic field to the target photon energy densities. Hence the radio flux from the secondary electrons for the GRBR model in Figure 2 does not violate the derived upper limit in so far as their IC emission is well below the observed TeV flux.

3. DISCUSSION AND PREDICTIONS

A GRBR should differ from a SNR not only by the energetics, but also by three characteristics of its relativistic particle population. First, the prompt differential spectrum of protons (and electrons) behind the relativistic shock cannot be a single power-law $N(E) \propto E^{-\alpha}$ with $\alpha \geq 2.0$ as in the case of non-relativistic shocks. As shocks with Lorentz-factor $\Gamma(t) \gg 1$ boost *all* particles they encounter to relativistic energies, the prompt spectrum should break to an index $\alpha_{1,\text{prompt}} < 1$ below some energy $E'_{\text{brk}} \lesssim m_p c^2 \Gamma^2(t)/2$ (observer frame) to satisfy the laws of energy and particle number conservation across the shock (Katz 1994). The final power-law index α_1 (presumably $\lesssim 1.5$) and the break energy E_{brk} are formed while the shock decelerates, and will depend on a number of processes, such as diffusive escape of relativistic protons from the shell, their adiabatic cooling and reacceleration, etc. At $E > E_{\text{brk}}$ a spectral index $\alpha_2 \approx 2.2$ is expected to form in Fermi-type processes (Kirk & Duffy 1999). For the current data, E_{brk} could be as high as 5 TeV (in Figure 2), but it could also be smaller, leading to GeV γ -ray fluxes detectable by GLAST.

The second feature of GRBRs that we predict is that a substantial fraction of the initial shock energy is eventually transferred to high-energy protons, while relativistic electrons would contain only a tiny fraction of it at times of non-relativistic evolution of the GRBR shell. A GRB shock becomes non-relativistic, and also quasi-spherical, on timescales $\lesssim 1 \text{ yr}$ at distances $\lesssim 0.1 \text{ pc}$ (Livio & Waxman 2000). At this stage, magnetic fields of $\sim 0.1 \text{ G}$ (Berger et al. 2004) are still high and will (synchrotron) cool electrons to a few GeV

within ~ 1 yr. As the initial kinetic energy $(5-10) \times 10^{51}$ erg of the jets is much larger than the radiated (and the magnetic field's) energy, by then most of it should be in relativistic protons. The evolution of a non-relativistic shell that is dominated by the relativistic energy, and not by the kinetic energy of the shock, requires a fully relativistic treatment and remains unexplored. Diffusion of relativistic protons (thus escaping adiabatic losses) upstream may broaden the shock precursor. Because of the preferential acceleration of particles with Lorentz factors larger than the precursor (Berezhko and Ellison 1999), energetic protons will readily be accelerated while acceleration of electrons will be suppressed. This would also apply to the spherical “supernova”-type component (which, however, may not be developed by GRBs at all, see MacFadyen & Woosley (1999)) as this non-relativistic shock has to pass through the central $\lesssim 10$ pc region dominated by the energy of relativistic protons from the (quasi-spherically opened up) GRB jets. We also note that in the presence of relativistic protons, nonrelativistic shocks may evolve (and dissipate) much faster than predicted by the standard Sedov-Taylor solution for SNR shocks propagating in “cold” plasmas (Toptygin 2000).

Third, considerable energy, $\sim (10-20)\%$, of the accelerated protons is channeled into collimated beams of neutrons (Atoyan and Dermer 2003; Dermer & Atoyan 2003) from interactions $p + \gamma \rightarrow n + \pi^+$ with X-ray photons from the GRB. First, this mechanism assures a minimum level of total energy of the protons that avoid adiabatic losses in the shell, $U_n \gtrsim 10^{51}$ erg. Furthermore, neutrons with energies E_n will β -decay into protons on length scales of $l_n(E_n) \simeq (E_n/100 \text{ TeV}) \text{ pc}$. A characteristic signature of a GRBR might then be an elongation of the TeV γ -ray emission due to conversion of the initial double-sided neutron beam into protons, which will subsequently be injected into the diffusion process along the jet path on length scales $\sim 1-10 \text{ pc}$ (for $E_n \lesssim 1 \text{ PeV}$). Depending on the contribution of neutrons to the high-energy proton pop-

ulation, the two-dimensional Gaussian profile may have an aspect ratio of up to $A = (\sigma_{\parallel} - \sigma_{\perp})/(\sigma_{\parallel} + \sigma_{\perp})$ with $\sigma_{\perp} = l_{\text{dif}}(E, t)$ and $\sigma_{\parallel} = \sqrt{l_n^2(E) + l_{\text{dif}}^2(E, t)}$. For a source size $l_{\text{dif}} \gtrsim 10 \text{ pc}$ this would predict $A(E) \sim (0.01-0.1)$. However, neutron beams can also affect the shape of the GRBR nebula indirectly via driving (after β -decay) the ISM, and stretching the ambient magnetic field, along the jet direction (Atoyan and Dermer 2003). A faster diffusion of the bulk of protons in this direction could result in $A(E) \gg 0.1$. Remarkably, in both cases the aspect ratio should increase at higher energies.

The HESS collaboration determined the source spectrum with the photons from the bright central part of the source (within $13.4'$ from the centre). While our model explains this spectrum, it predicts that the energy spectrum will be significantly harder when determined for the entire source (see Figure 2). Another specific signature of a GRBR is the unusually hard energy spectrum at $E \leq E_{\gamma, \text{brk}} \sim 10-100 \text{ GeV}$. GLAST will be able to verify or falsify this prediction. If HESS J1303-631 is a SNR, GLAST will easily detect the source at the flux level close to the upper limit of EGRET (Mukherjee & Halpern 2005). However, a weak detection (confirming the hard spectrum) or non-detection by GLAST would signify the tell-tale detection of the signatures of proton acceleration by relativistic shocks of a GRB.

Confirmation of HESS J1303-631 and at least one other extended unidentified TeV source, such as TEV J2032+4130 (Aharonian et al. 2002; Lang et al. 2004), as GRBRs would confirm the high rate, of order 10^{-4} yr^{-1} , of Galactic GRBs, and would make it more likely that GRBs had a direct impact on life on Earth (Melott et al. 2004).

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